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Changes of MOISTURE AND TEMPERATURE UNDER A CONCRETE SLAB FLOOR in an Expansible Farmhouse

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PREFACE

This publication is one of a series reporting on studies in five expansible-type houses built at the Agricultural Research Center, Beltsville, Md., during the period 1952-54. Two publications have been issued: ARS-42-45, Evaluation of Construction, Materials, and Livability of Five Expansible Farmhouses; and ARS-42-46, Some Effects of Construction and Climatic Factors on Heating Expansible Farmhouses.

This publication is the final report on studies of moisture movement under concrete slab floor in one of the experimental houses--House E. Construction details of the house are given in the above publications. Tests were run in the house for almost a year prior to occupancy (November 1955) and were continued for 2 additional years. Thus, the results of research in this house, as in the others, were affected by family living characteristics as well as by weather and soil and indicate in-use performance under the conditions at the site.

A preliminary report entitled "Moisture Movement Under a Concrete Floor in an Experimental Farmhouse," by H. J. Thompson and A. A. Biggs was presented at the Annual Meeting of the American Society of Agricultural Engineers, at Roanoke, Va., in June 1956.

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of J. R. Dodge, formerly with this Division, who initiated the study. They are particularly grateful to Wallace Ashby, retired, formerly Chief, Livestock Engineering and Farm Structures Research Branch, for his assistance in the conduct of the study.

The contributions of industry in supplying certain materials for the construction of this house are also gratefully acknowledged.

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CHANGES OF MOISTURE AND TEMPERATURE UNDER A CONCRETE SLAB FLOOR IN AN EXPANSIBLE FARMHOUSE

By Harold J. Thompson, agricultural engineer,[1] Archie A. Biggs, architect, and Joseph W. Simons, agricultural engineer, Livestock Engineering and Farm Structures Research Branch, Agricultural Research Division

Concrete slab floors laid on the ground or over fill have been used extensively in residential construction in recent years. Although not limited to low-cost construction, concrete slab floors have gained greatest prominence in that field.

Cost comparisons of concrete slab floors with floors of more conventional construction have been and are being made by various organizations and by individual builders. Temperature studies of concrete slab floors and conventional suspended wood floors have been made under both summer and winter conditions by the U.S. Department of Agriculture[2] and others. The USDA investigations were limited in extent and neither soil temperatures nor their effect on heating requirements or on maintaining uniform temperatures were studied.

The U.S. Public Housing Agency[3] believes that heated slabs on grade are increasing termite problems in northern regions because soils warmed by houses permit termite activity more months of the year. Thus, a knowledge of soil temperatures under concrete floors on the ground is essential to an understanding of many problems.

Very little research has been conducted on moisture movement through and under concrete slab floors, and on vertical movement of the slab due to changes in ground moisture. The use of vapor barriers on foundation and basement walls and under slabs on grade has presented problems of a fundamental nature. Experienced contractors do not have sufficient information to decide what kind of barrier is needed, where it should be placed, and how much and what kind of fill materials should be used. Measurement of moisture transmission through many materials is not an exact science. However, such measurements, although not exact, would be of value in assessing the effect of moisture movement on the humidity within the house, and on floor temperatures and heat losses through the floor.

The U.S. Forest Products Laboratory made a brief study[4] with small containers simulating concrete slabs on grade. Their research raised additional questions about the requirements for vapor barriers. Virtually no information is available regarding the initial effectiveness of barriers, and their rates of deterioration and effective life.

Damage due to movement of soil moisture into the above-ground part of the structure is sometimes serious. Soil moisture accumulation appearing as free water or as condensation near or on the structure can be detrimental.

[1] Mr. Thompson is now with the Administrative Services Division, ARS; USDA.

[2] Simons, J. W., and Lanham, F. B. Factors Affecting Temperatures in Southern Farmhouses. U.S. Dept. Agr. Tech. Bul. 822, (rev.), 91 pp., 1951.

[3] Comments by R. Skayesberg at a meeting of the Special Federal Government Committee for Study of Concrete-Slab-on-Grade Construction. FHA, Washington, D.C., Nov. 4, 1955.

[4] Russell, William A. Moisture Migration From the Ground. Housing Research Paper 28, 13 pp. Housing and Home Finance Agency, 1954.

FACILITIES AND METHODS

The study was conducted in House E, one of five experimental houses at the Agricultural Research Center, Beltsville, Md. This house is a one-bedroom wood frame structure with corrugated aluminum exterior and plywood interior. The walls are insulated with aluminum foil. Exposed rafters covered with insulating sheathing and corrugated aluminum form the ceiling and roof. The house was airconditioned by a heat pump during the entire period covered by this report. The temperature within all rooms was about 75° or 76° F. for the heating season and a few degrees cooler during the summer.

The house was unoccupied during tests made between November 1954 and November 1955. In October 1955 the concrete floor was covered with 8- by 8-inch vinyl tile.

Rainfall data were obtained from U.S. Weather Bureau readings at Beltsville, Md., for the period of study (table 1). Eave troughs, downspouts, and tile drains reduced variability of soil moisture due to direction of the rains.

The soil on the experimental house site is a sandy loam and in some places is quite sandy or gravelly at depths of 3 or 4 feet. A thin layer of soft rock extends over part of the area at a depth of about 6 feet. Figure 1 shows the topography of the site.

Figure 2 shows the plan of the floor slab divided into 12 test bays, the method of dividing the bays, and the floor and foundation construction. Each test bay covers an area of about 5 by 12 feet. Eight bays have gravel fills and the remaining four have earth fills. Four of the gravel bays have 3/8-inch breather tubes in the foundation walls. The six bays at the east end of the house have a vapor barrier of 55-pound asphalt saturated crawl space cover, which has a permeance of 0.30 perm. The vapor barrier material is lapped 3 inches and the joints are sealed. The other six bays have no vapor barrier.

TABLE 1.--Rainfall by months, Beltsville, Md., December 1954-September 1957

Year and month	Rainfall	Year and month	Rainfall
	Inches		Inches
1954: December	2.62	1956:	
1955:		May	2.38
January	.18	June	4.67
February	2.84	July	5.47
March	3.2	August	1.72
April	2.53	September	3.37
May	1.99	October	3.25
June	6.08	November	3.21
July	1.94	December	3.24
August	16.15	1957:	
September	.87	January	2.54
October	6.15	February	2.51
November	1.22	March	3.01
December	.13	April	2.98
1956:		May	2.11
January	2.41	June	4.27
February	2.99	July	1.71
March	3.90	August	3.25
April	1.81	September	.0

[1] U.S. Weather Bureau data.

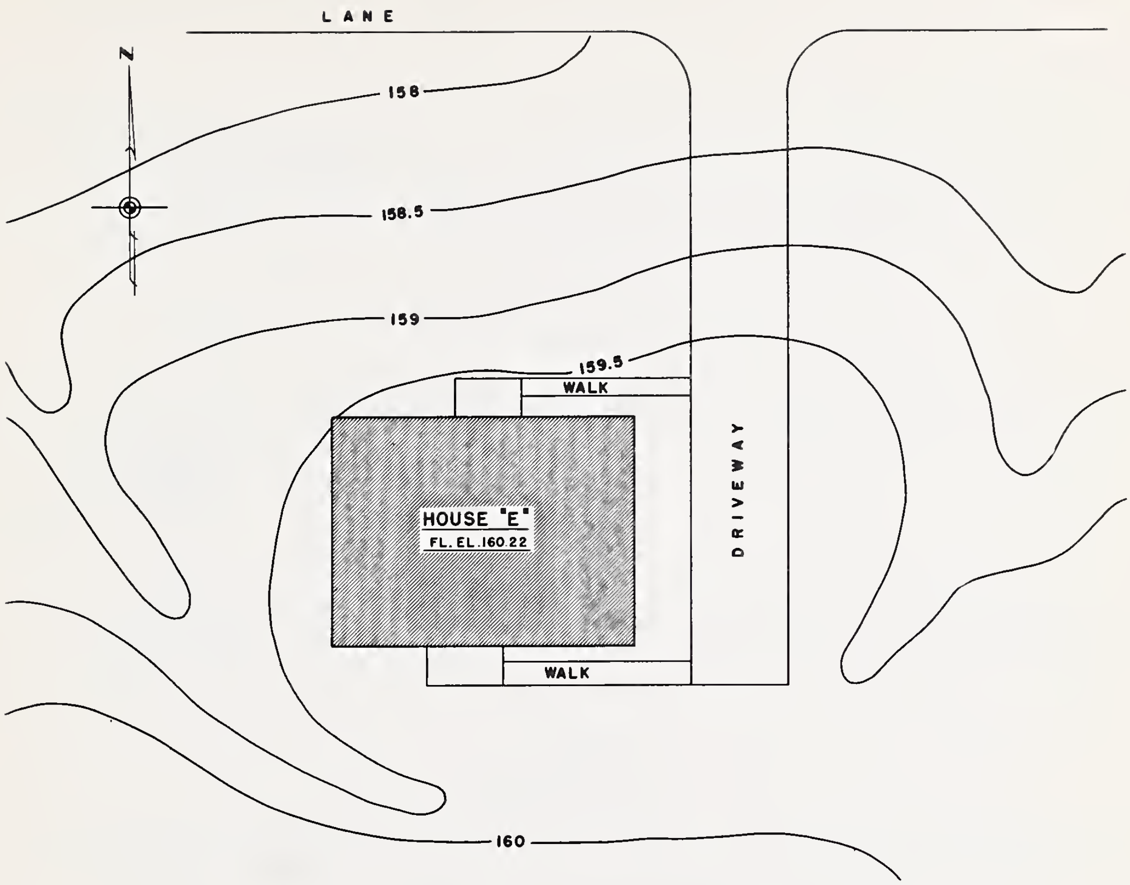

Figure 1.--Topographic site plan.

Random assignment of treatments for the bays was not possible because of (1) the necessity of sealing or making continuous the vapor barrier on one-half of the slab, (2) slab end and corner effects, and (3) the complication of east-west or lateral heat transfer in the fill and the slab. Vapor transfer between bays in the fill and subgrade was minimized by galvanized sheet metal dividers that extended approximately 2 feet into the subgrade, as indicated in figure 2. No division could be made in the concrete between the bays.

Moisture and temperature measurement stations were provided 2 inches below the underside of the 4-inch slab floor, as indicated in figure 2. In the four earth bays, readings were also taken 22 inches below the slab. Measurements outside the foundation walls were made at a depth of 22 inches.

Measurement of Moisture Under Concrete Slab and at Other Locations in Soil

Nylon plaster-of-Paris electrical conductivity elements developed by Bouyoucos[5] were used to measure soil moisture. Readings were taken with a 1,000-cycle per second impedance bridge. Soil-moisture calibrations for specific soils are not needed to compare tension or water movement potentials if it is assumed that all elements in a given setup have comparable tension-impedance characteristics.

[5] Bouyoucos, G. J. Newly Developed Nylon Units for Measuring Soil Moisture in the Field. Highway Research Abstracts, 31 pages, 1954.

FILL TREATMENTS FOR 12 TEST BAYS IN PLAN

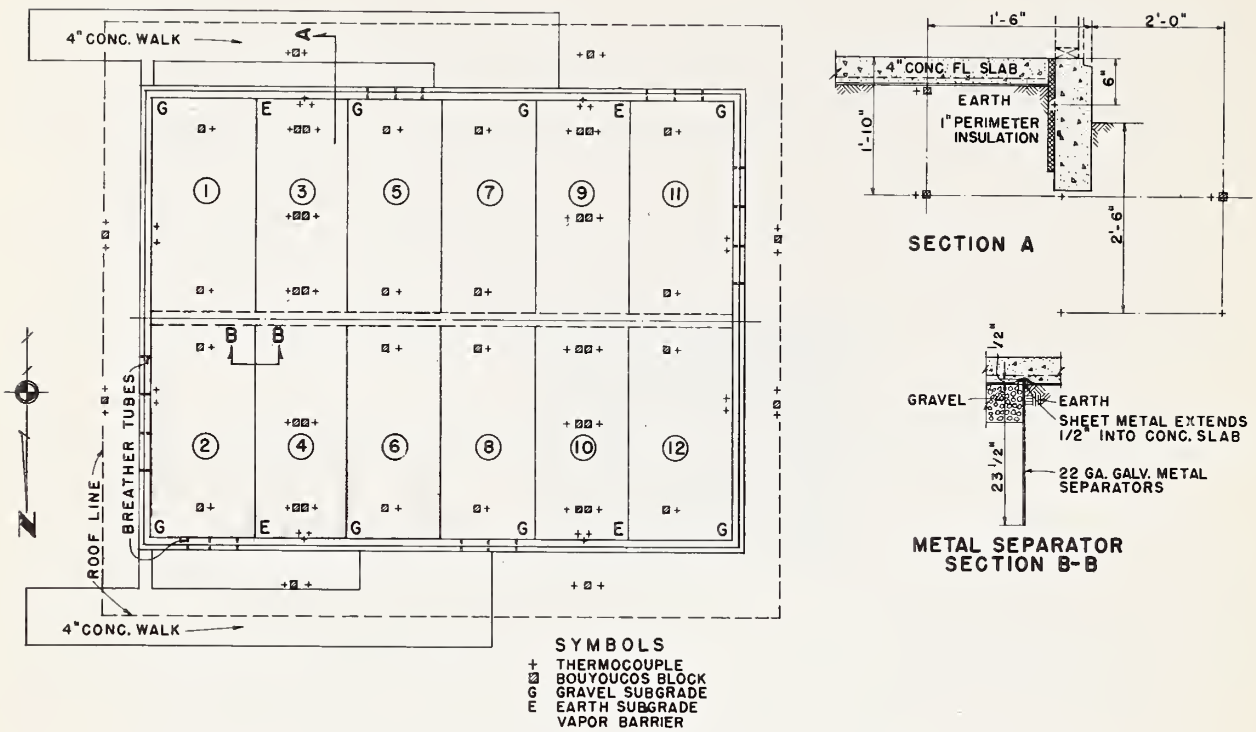

Figure 2.--Plan of floor slab, method of dividing the bays, and foundation and floor construction details.

Moisture samples taken outside the foundation varied greatly because of differences in soils, which ranged from sand strata to dense clay. Therefore, soil-moisture data in the tables are given either in terms of the logarithm to the base 10 of the element impedance in ohms, or soil-moisture index (10 minus $\log_{10}$ ohms); this was done partly because tension characteristics are not too well defined in the upper levels of soil moisture. Data in the graphs are in terms of soil-moisture index. The higher the index the higher the moisture content.

The moisture elements were originally designed to work in contact with soil. Therefore, readings of elements placed in the gravel beds can only indicate free water, condensation water, and water vapor equilibrium in the void spaces, since capillary tension would not be effective in gravel. For this reason too much reliance cannot be placed on a direct comparison of soil-moisture measurements between earth and gravel fills.

Moisture measurements were made approximately once each month from December 1954 through September 1957.

Electrical Conductivity Measurements in the Concrete Slab Floor

Measurements on electrical conductivity within the concrete slab were made at two depths. Stainless steel electrodes or pins, 1/8-inch in diameter, were cast in pairs $1\frac{1}{2}$ inches apart in the concrete; contact with the concrete was made only at the lower end of the pins. Sets of these pins were installed halfway between top and bottom, and at a depth of 3-3/4 inches in the 4-inch slab. The impedance for the pins was read with the same bridge used for reading the soil-moisture elements. Calibration of the moisture content of the concrete versus electrical conductivity was not attempted.

Blotter Measurement of Moisture Transmission Through the Floor

This limited study was another approach to the problem of measuring moisture transmission through concrete slab floors. Ordinary 4- by 9-inch blotters were weighed on an analytical balance to within about 5 milligrams and were then exposed to the room air before they were placed on the tiled floor of all 12 bays. The blotters were covered with pieces of aluminum-foil-faced building paper 18 inches square. About 7 days was required for them to reach constant weight. They were then ovendried at 110° C. to constant weight, and the moisture they had adsorbed was calculated.

Measurement of Temperatures

Measurements of underfloor and subgrade temperatures were taken to within $\pm$ 1° F. approximately once each month during the 3-year period, by means of copper-constantan thermocouples. Air temperatures within the house and an average of floor surface temperatures were recorded at 2-hour intervals throughout most of the period under study.

Measurement of Floor Slab and Foundation Wall Movement

Elevations of the foundation wall were obtained with a surveyor's level at irregular intervals from December 17, 1954, to November 10, 1955. Floor slab elevations were taken only during the 6-month period February 28 to August 26, 1955.

Measurement of Water Table

Attempts were made to measure the water table through pipes installed in the ground near the four corners of the house. Readings at the four corners varied widely at times so no attempt was made to plot the data or compare them with other data.

RESULTS

Moisture Changes Under Concrete Slab Floor

Table 2 summarizes, for the period December 1954 to September 1957, the averages for comparable bays of the impedance readings of moisture elements located primarily 2 inches and 22 inches below the concrete slab floor. Tables 3 and 4 show moisture index and temperature readings for center and perimeter locations in selected bays 2 inches below the concrete slab floor in earth and gravel fills.

Only interior bays were selected for a detailed study because the end bays were exposed on one side in addition to the end. Bays with breather tubes in the foundation wall were not selected in order to eliminate this variable. Aside from the influence of directional exposure (i.e., north versus south) and possibly room environment differences, the results for bays with and without vapor barriers can be compared with some confidence as to absence of conflicting factors which would be difficult to correct for.

In general, the data for the selected bays show somewhat similar trends to the averages of impedance readings given in table 2. Actually the data for selected bays present a more accurate picture, since averages tend to mask the true results. The application of vinyl tile to the floor of this house may have masked differences that might have resulted from the use of vapor barriers.

The curves in figure 3, plotted from data in table 3, for earth fill show that the moisture index trend is downward with time except in the center of the bay without vapor barrier (Bay 9), which showed a slightly upward trend. In spite of the upward trend for

TABLE 2.--Impedance readings of nylon plaster-of-Paris elements under concrete slab[1]

[Average $\log_{10}$ ohms]

Date	Exterior, 22 inches deep	Gravel, 2 inches deep		Gravel, 2 inches deep[2]		Earth, 2 inches deep		Earth, 22 inches deep	
		Bays 1 and 6, vapor barrier	Bays 7 and 12, no vapor barrier	Bays 2 and 5, vapor barrier	Bays 8 and 11, no vapor barrier	Bays 3 and 4, vapor barrier	Bays 9 and 10, no vapor barrier	Bays 1 to 6	Bays 7 to 12
1954:									
Dec. 16	2.3	4.85	3.78	5.05	4.59	3.48	3.58	2.3	2.3
Dec. 29	2.3	5.14	4.29	5.17	4.60	3.30	3.46	2.3	2.4
1955:									
Feb. 4	2.9	5.03	4.60	5.73	5.06	2.40	3.17	2.3	2.4
Mar. 3	2.3	5.57	4.47	5.66	5.01	2.69	3.07	2.3	2.3
Mar. 23	2.3	5.27	4.64	5.90	4.91	2.64	2.98	2.3	2.3
Mar. 24	2.3	5.51	4.09	5.73	5.07	3.26	2.97	2.3	2.3
Apr. 15	2.3	5.53	4.52	5.93	5.10	2.61	2.97	2.3	2.3
May 12	3.2	5.61	4.24	5.63	4.86	2.60	2.97	2.3	2.1
June 2	4.1	5.21	3.50	5.53	5.31	2.56	2.97	2.3	2.3
June 21	4.0	5.52	4.07	5.46	5.26	2.70	2.98	2.3	2.3
July 26	4.3	4.79	3.74	6.00	4.71	2.59	2.98	2.3	2.3
Aug. 23	2.3	4.82	3.27	4.98	4.71	2.31	2.70	2.3	2.3
Sept. 20	3.1	4.62	3.21	4.67	4.34	2.30	2.64	2.3	2.3
Oct. 27	2.3	3.87	3.17	4.72	3.91	2.30	3.50	2.3	2.3
Nov. 2	2.3	3.97	2.30	4.63	3.89	2.30	2.89	2.3	2.3
Nov. 8	2.3	4.04	4.11	4.64	3.82	2.30	2.77	2.3	2.3
Dec. 27	2.3	3.90	3.85	4.53	3.70	2.56	2.97	2.3	2.3
1956:									
Jan. 31	2.3	4.64	3.44	4.87	4.66	2.60	2.90	2.3	2.3
Feb. 28	2.3	4.70	3.94	4.88	4.94	2.70	2.98	2.3	2.3
Mar. 27	2.3	4.79	4.44	5.12	4.89	2.66	3.04	2.3	2.3
Apr. 27	1.1	4.58	3.73	4.91	4.76	2.66	3.28	2.3	2.3
June 29	2.8	4.27	3.61	4.69	4.64	2.74	3.20	2.3	2.3
Aug. 1	3.0	3.98	3.80	4.54	4.82	3.25	3.30	2.3	2.3
Sept. 4	3.7	4.08	3.68	4.46	4.60	3.46	3.31	2.3	2.3
Oct. 2	3.6	3.97	3.69	4.67	4.73	3.52	3.81	2.3	2.3
Oct. 30	3.7	3.91	3.76	4.84	4.62	3.59	3.53	2.6	2.3
Dec. 4	2.3	3.66	4.06	4.77	4.48	3.65	3.59	2.7	2.3
1957:									
Jan. 8	2.3	3.74	4.18	4.75	4.53	3.67	3.77	2.5	2.3
Feb. 5	2.3	3.76	4.29	4.59	4.92	3.68	3.94	2.3	2.3
Mar. 4	2.3	3.77	4.29	4.75	4.46	3.73	4.05	2.5	2.3
Apr. 2	2.3	4.09	4.21	5.08	4.27	3.78	4.13	2.4	2.3
Apr. 26	2.4	4.07	4.05	4.73	4.70	3.54	3.96	2.5	2.6
May 28	3.3	4.14	4.06	4.62	4.66	3.75	4.01	2.6	2.9
July 2	3.7	3.76	3.99	4.52	4.62	3.73	4.01	2.8	2.8
July 30	4.0	3.72	3.74	4.46	4.55	3.80	4.05	2.9	2.8
Sept. 2	4.1	3.66	4.01	4.55	4.54	3.81	4.15	2.6	2.9

[1] For exterior readings, elements were 24 inches from foundation.
[2] Bays 2, 5, 8, and 11 had 3/8-inch breather tubes placed through the foundation walls. However, the tubes in bays 5 and 11 were covered in grading the site and were considered inoperative.

the center of this bay, the moisture index averaged considerably lower than the index for the perimeter in the same bay and lower than either center or perimeter for the bay with a vapor barrier. The lower index under the center of the concrete slab without barrier would normally be expected if the rate of moisture transfer through the slab is appreciable and if the lateral rate of moisture transfer from the perimeter is slow. The maximum level could not be considered as low, however, since the index represents a moisture content of slightly more than 24 percent, or about field capacity. Field capacity is the maximum amount of water a well-drained soil can retain under normal field conditions. The high readings of the other curves for the earth fill represent saturation level or standing water.

Moisture contents for the perimeter were undoubtedly affected more by external conditions than were those for the center. Nevertheless, at the end of the study the moisture indexes for earth bays with and without vapor barriers appeared to be approaching equilibrium--somewhere between 5.4 and 5.8, which represents approximately field capacity.

No change can be noted in three of the earth bay curves as a result of laying floor tile or occupancy of the house in October and November 1955. It is not believed that the

TABLE 3.--Temperature and moisture index readings at center of house and perimeter, locations, 2 inches below the concrete slab floor in earth fill.

Date	PERIMETER				CENTER			
	Bay 3 (kitchen) vapor barrier		Bay 9-utility rm no vapor barrier		Bay 3-kitchen vapor barrier		Bay 9-hall[1], no vapor barrier	
	Temperature	Moisture index[2]	Temperature	Moisture index[2]	Temperature	Moisture index[2]	Temperature	Moisture index[2]
	°F.		°F.		°F.		°F.	
1954: Dec. 17	57	7.16	55	6.70	62	6.46	61	5.15
1955:								
Feb. 2	54	7.40	53	7.40	60	7.00	60	5.35
Mar. 2	61	7.70	55	7.70	61	7.30	60	5.48
Apr. 15	64	7.70	62	7.70	66	7.38	64	5.52
May 12	63	7.70	63	7.66	64	7.38	64	5.58
June 2	67	7.40	66	7.64	68	7.40	66	5.60
June 21	71	7.70	68	7.70	71	7.42	68	5.60
July 26	74	7.66	73	7.66	73	7.40	72	5.72
Aug. 23	72	7.66	73	7.70	72	7.70	72	5.70
Nov. 9	67	7.70	64	7.70	67	7.70	67	5.82
Dec. 27	63	6.40	62	7.70	70	7.70	69	6.00
1956:								
Jan. 31	64	6.19	61	7.70	72	7.70	68	6.00
Feb. 28	64	6.10	63	7.10	70	7.70	69	6.00
Mar. 27	63	6.00	61	7.00	70	7.70	68	6.00
Apr. 27	66	5.89	66	7.00	71	7.70	70	5.96
May 29	69	--	69	--	72	--	71	--
June 29	75	--	74	--	75	--	74	--
Aug. 1	73	5.82	73	6.12	73	6.52	73	6.10
Sept. 4	73	5.70	75	6.05	73	6.30	75	6.15
Oct. 2	70	5.72	72	6.00	72	6.15	73	6.10
Oct. 30	69	5.72	68	5.89	72	6.05	71	6.10
1957:								
Jan. 8	62	5.57	62	5.92	70	5.96	69	6.00
Mar. 4	63	5.46	61	5.70	69	5.92	68	5.82
Apr. 2	66	5.46	66	5.60	71	5.77	70	5.82
Apr. 26	68	5.60	69	5.82	72	5.85	72	5.89
May 28	71	5.52	72	5.77	73	5.92	74	5.80
July 2	73	5.40	74	5.85	74	5.80	75	5.89
July 30	75	5.46	76	5.82	75	5.80	76	5.89
Sept. 3	76	5.40	76	5.66	76	5.70	76	5.85
Averages through Nov. 9, 1955	65.0		63.2		66.4		65.4	
Averages after tile laid and after occupancy (Dec. 27, 1955 on)	68.6		68.4		72.1		71.7	
Averages, entire period, Dec. 17, 1954-Sept. 3, 1957	67.3		66.7		70.1		69.5	
Averages, winter months before tile and occupancy	59.0		56.3		62.3		61.3	
Averages, winter months after tile and occupancy	64.8		64.1		70.7		69.5	

[1] Middle of bay.
[2] 10 minus $\log_{10}$ ohms.

rapid drop in moisture index at the perimeter of the vapor barrier bay, which occurred at about that time, was caused by these factors.

No consistent trend in moisture index is shown by all curves for gravel fill in figure 3. With vapor barrier the perimeter maintained a fairly uniform level through most of the period whereas the center showed a definite upward trend. Without vapor barrier the perimeter showed a wide variation with a general upward trend whereas the center indicated a downward trend. These trends are in contrast to the results for earth fill which, after the first year and a half, appeared to be approaching an equilibrium value regardless of location or vapor barrier treatment. Some of the variation, particularly in perimeter readings, might be explained as temperature effect since with these elements, temperature would have a greater influence on the measurement of vapor pressure in gravel void spaces than in earth. External conditions appeared to have less effect on the center indexes.

Erratic behavior of elements in gravel may be expected since the elements were designed to be used in intimate contact with earth where they would be less subject to comparatively rapid changes in temperature and moisture. Some of this erratic behavior may be due to condensation on the element surface which would decrease the impedance.

TABLE 4.--Temperature and moisture index readings at center of house and perimeter locations, 2 inches below the concrete slab floor in gravel fill

Date	PERIMETER				CENTER			
	Bay 6 (living room) vapor barrier		Bay 7-utility room no vapor barrier		Bay 6-living room vapor barrier		Bay 7-hall no vapor barrier	
	Temperature	Moisture index[1]	Temperature	Moisture index[1]	Temperature	Moisture index[1]	Temperature	Moisture index[1]
	°F.		°F.		°F.		°F.	
1954: Dec. 17	54	5.00	56	6.27	61	5.30	62	7.70
1955:								
Feb. 2	49	4.46	52	4.30	60	5.40	60	7.70
Mar. 2	60	4.10	57	5.22	55	5.52	61	7.70
Apr. 15	61	4.10	64	4.52	65	5.70	65	7.70
May 12	62	4.00	64	5.15	64	5.72	64	7.70
June 2	66	4.12	67	5.22	67	5.74	67	7.70
June 21	69	4.15	70	5.30	69	5.70	70	7.70
July 26	73	4.74	73	5.80	71	5.70	72	7.70
Aug. 23	71	4.30	74	7.70	71	5.96	72	7.70
Nov. 9	61	4.19	63	7.70	65	6.70	66	7.70
Dec. 27	57	5.00	59	7.30	68	6.82	69	7.70
1956:								
Jan. 31	59	4.89	61	5.40	69	6.60	70	7.70
Feb. 28	62	4.60	62	5.30	69	6.60	70	7.70
Mar. 27	60	4.30	60	5.22	68	6.82	69	7.70
Apr. 27	64	4.60	65	5.52	70	6.60	71	7.70
May 29	68	--	68	--	70	--	70	--
June 29	73	--	73	--	73	--	74	--
Aug. 1	71	4.82	71	6.66	71	6.40	71	6.00
Sept. 4	72	4.30	74	7.22	72	6.52	74	6.05
Oct. 2	67	4.43	70	7.40	71	6.60	72	5.92
Oct. 30	66	4.42	69	7.36	71	6.77	72	5.89
1957:								
Jan. 8	60	4.40	60	5.77	68	7.62	69	5.92
Mar. 4	60	4.26	59	5.82	68	7.70	69	5.70
Apr. 2	64	4.22	64	5.82	69	6.70	71	5.70
Apr. 26	67	4.60	69	6.10	71	7.52	69	5.92
May 28	69	4.21	72	6.15	71	7.40	73	5.70
July 2	71	5.46	73	6.40	72	7.30	73	5.70
July 30	74	5.52	76	7.22	74	7.30	76	5.82
Sept. 3	72	5.57	76	6.46	73	7.40	75	5.60
Average through Nov. 9, 1955	62.6		64.0		64.8		65.9	
Average after tile laid and after occupancy (Dec. 27, 1955 on)	66.1		67.5		70.4		71.4	
Average for entire period Dec. 17, 1954-Sept. 3, 1957	64.9		66.3		68.5		69.5	
Average winter months before tile and occupancy	56.0		55.8		60.3		62.0	
Average winter months after tile and occupancy	61.7		62.7		69.1		70.1	

[1] 10 minus $\log_{10}$ ohms.

With certain temperature changes, lowering the dewpoint would tend to decrease the vapor pressure of the void space.

Little change occurred in the moisture index in the earth subgrade 22 inches below the slab, until October 1956 for the bays with vapor barrier and until April 1957 for no-barrier bays, as indicated in table 2. Conversion of moisture index values indicates that moisture contents ranged from about 24 percent (field capacity) to 42 percent (standing water); thus the soil 22 inches below the slab appeared to be saturated during the entire period, December 1954 to September 1957.

Some seasonal changes occurred at the 22-inch depth outside the foundation, as indicated in figure 4. No definite pattern is indicated for the changes occurring 2 inches below the slab. Conversion of the element readings to moisture contents indicated that the soil outside the foundation as well as below the slab was higher in moisture content than would normally be expected over a period of almost 3 years. Two of the eight moisture elements were either under or close to the edge of the concrete sidewalks, and these moisture indexes were higher than those not under the sidewalk. These higher moisture indexes may have been partly the result of watering flower beds in that area.

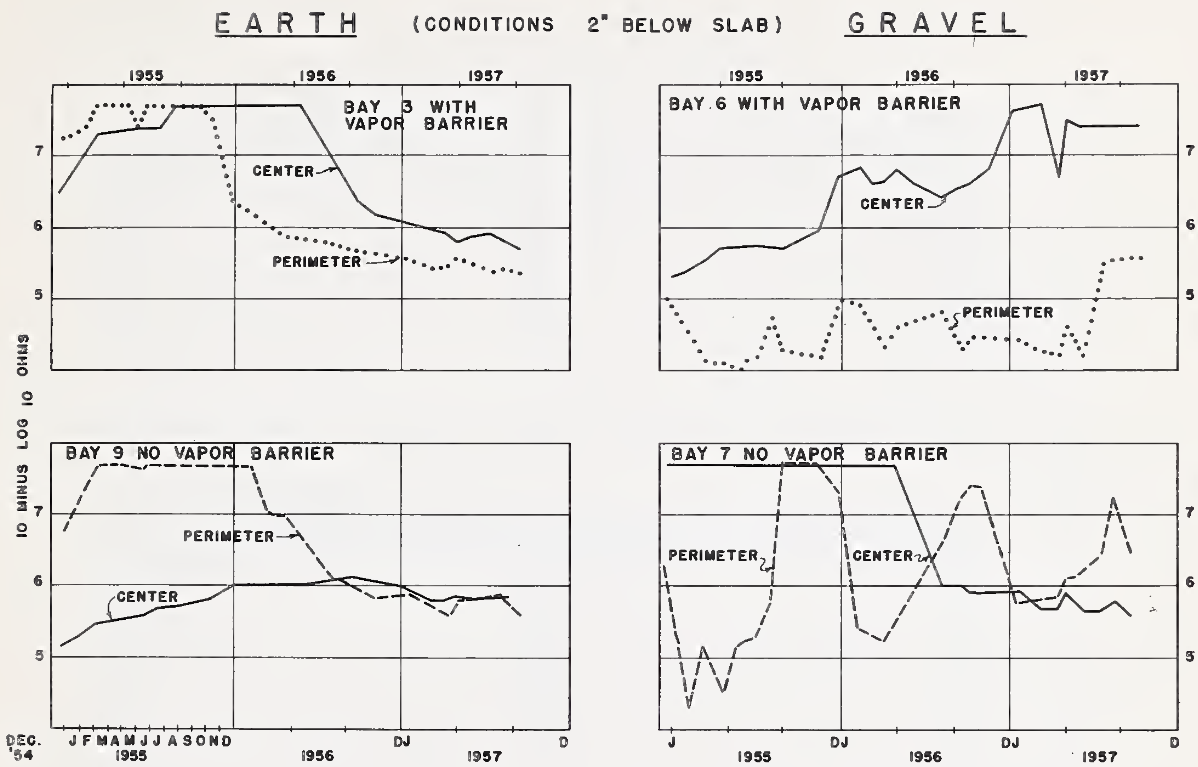

Figure 3.--Moisture indexes in earth and gravel fills 2 inches below slab floor.

In spite of moisture changes at the 22-inch level outside the foundation wall, the moisture content of the earth 22 inches below the slab tended to decrease slightly with time although during most of the period it was always as high as the outside reading or higher. Average moisture indexes 2 inches under the slab were lower about two-thirds of the time than those outside 22 inches deep.

Breather tubes in the foundation walls of the gravel bays seemed to have some effect in maintaining slightly lower average soil moisture indexes. The ends of part of the breather tubes were covered when the site was graded, which restricted vapor movement through these tubes. Even though average moisture indexes increased with time for the bays with breather tubes, these readings were slightly lower than for bays without breather tubes through September 1957. With the upward trend of average readings for the bays with breather tubes and the downward trend for the bays without breather tubes, it is possible that the curves would eventually cross and the breather tubes would thus result in higher moisture vapor. When fills are not ventilated, the continual heating of the slab tends to increase the temperature and eventually reduce the moisture content by lateral or vertical movement to cooler areas.

Electrical Conductivity Changes in Concrete Slab Floor

Table 5 (appendix) summarizes moisture data obtained by measurements taken on the steel pins in the concrete slab. The data from which the summary was made are plotted by months in figure 5. There is little difference in the conductivity levels at the mid-point (M) of floor slabs comparing one earth and two gravel fill treatments. Differences between medium (M) and long (L) pin readings indicate a general upward movement of moisture through the slab. All curves indicate a general upward trend of moisture index with time. According to these measurements, the south bays contained more moisture than the north bays. Actually, the moisture level may not have been higher

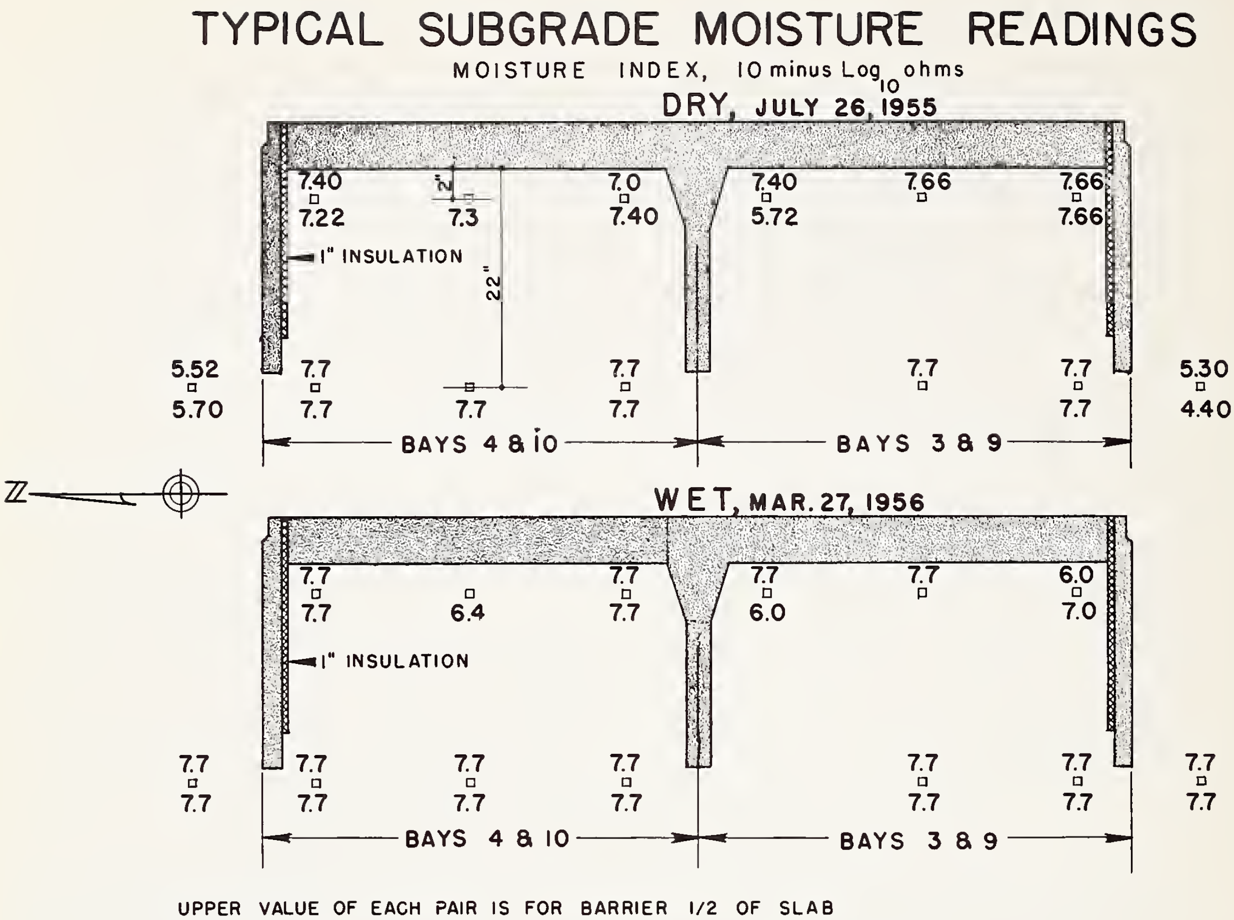

Figure 4.--Effect of season on earth subgrade moisture index.

but the vapor pressure may have been higher because of the higher temperature of the kitchen and bathroom floors.

Although the measurements are a function of moisture content, the differences may not always indicate the rate of vapor transfer, since permeability may also be affected by moisture content. The lower side of the slab was apparently somewhat drier over gravel bays than over earth bays, especially for the bays with no-vapor barrier. A comparison of differences due to vapor barriers over gravel bays shows somewhat opposite effects than would be expected. The concrete showed more moisture in bay 1 with vapor barrier than in bay 12 without vapor barrier. This is not logical, and the only reasonable explanation is the possible effect of north versus south exposure. The difference, however, is not great and might be due to error in measurement. An inherent source of error for this type of measurement is the possibility of encountering pieces of gravel between pins which would cause changes in electrical resistance.

Blotter Measurement of Moisture Transmission Through Floor

Table 6 gives the moisture absorbed by blotters laid over the tiled floor, and provides a relative means of comparing the moisture conditions at the surface of the floor for the 12 bays. In all six pairs of bays the vapor barrier reduced absorption, the average decrease being about 20 percent. The wide range of differences suggests that this set of measurements can only be considered exploratory. The measurements do not indicate the rate of transfer accurately since after equilibrium weight has been

TABLE 5.--Moisture index of concrete at two depths, earth and gravel fills with and without vapor barriers

[10 minus $\log_{10}$ ohms between pairs of electrodes 1-1/2 inches apart at midpoint (M) and at 3 3/4-inch depth (L) in a 4-inch slab; each value is an average of 9 logarithms to base 10 representing readings from March 23 to October 27, 1955]

Type of fill	Bay No.	Perimeter[1]			Center[2]			Average, M
		M	L	Difference	M	L	Difference	
Gravel fill:								
Vapor barrier...........	1, SE	6.28	6.26	0.02	6.04	6.43	-0.39	6.16
No vapor barrier........	12, NW	5.92	5.95	-.03	[3] 6.12	6.31	-.19	6.02
Gravel fill with breather tubes:[4]								
Vapor barrier...........	5, S	6.00	--	--	6.09	6.14	-.05	6.04
No vapor barrier........	8, N	5.95	--	--	6.12	6.52	.40	6.03
Earth fill:								
Vapor barrier...........	4, N	5.97	6.40	-.43	6.11	--	--	6.04
No vapor barrier........	9, S	6.43	6.73	-.30	6.22	--	--	6.32

[1] Near long edges of house slab.
[2] Near long axis of house slab.
[3] Center M value for Bay 8.
[4] 3/8-inch breather tubes in outside foundation walls; outer end of Bay 5 tubes covered with soil.

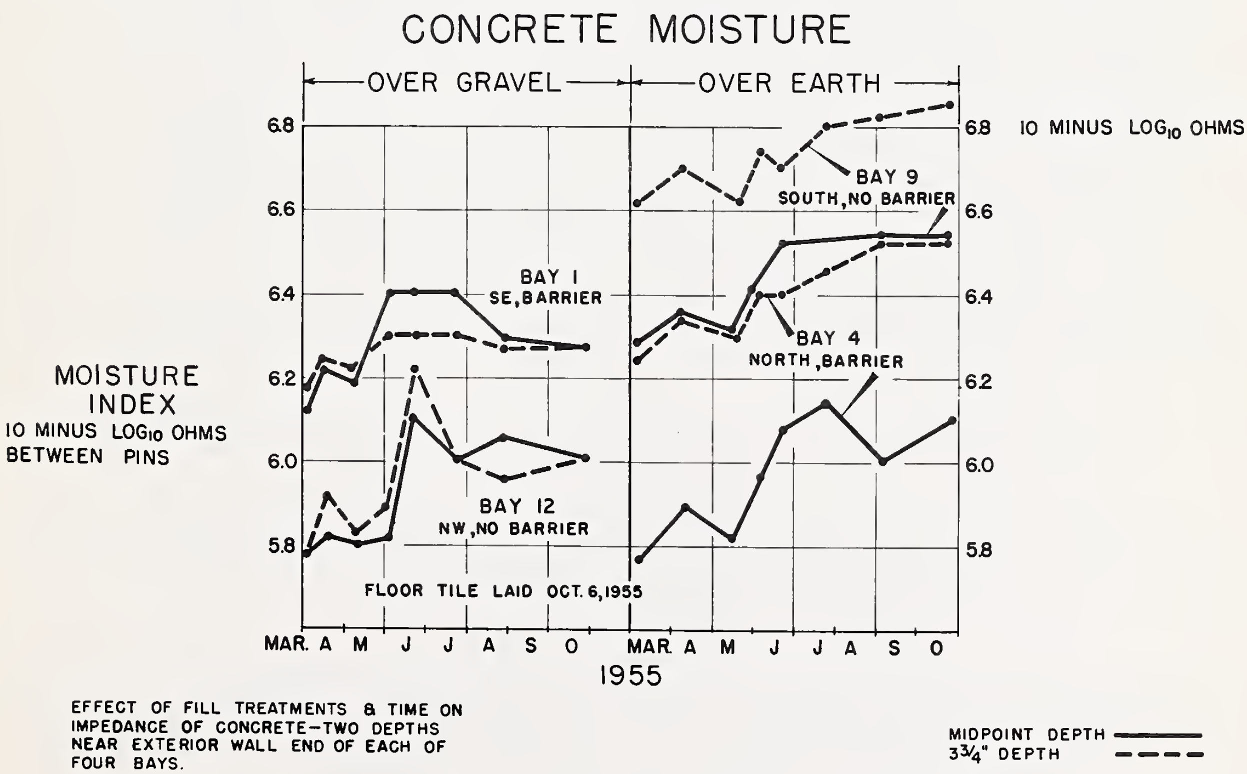

Figure 5.--Concrete moisture over several gravel and earth bays.

TABLE 6.--Moisture absorbed by blotters laid on surface of floor tile and covered with aluminum foil taped to floor in 12 test bays, October 1955

Location of blotters	Bay No.	Moisture	Difference
South side			
		Grams	Percent
Gravel fill:			
No vapor barrier	7	0.465	--
Vapor barrier	1	.335	--
Difference	--	.130	39
Gravel fill with breather tubes:[1]			
No vapor barrier	11	.389	--
Vapor barrier	5	.325	--
Difference	--	.064	20
Earth fill:			
No vapor barrier	9	.376	--
Vapor barrier	3	.318	--
Difference	--	.058	18
North side			
Gravel fill:			
No vapor barrier	12	.379	--
Vapor barrier	6	.365	--
Difference	--	.014	4
Gravel fill with breather tubes:[1]			
No vapor barrier	8	.403	--
Vapor barrier	2	.352	--
Difference	--	.051	14
Earth fill:			
No vapor barrier	10	.417	--
Vapor barrier	4	.336	--
Difference	--	.081	24

[1] 3/8-inch breather tubes in outside foundation walls.

reached, vapor transfer through the portion of the slab covered by the blotter ceases except for edge effects.

Temperatures Under Concrete Floor Slab and in Soil at Other Locations

The house was built in the summer of 1954 and soil temperature records were not started until December 1954; therefore, initial temperatures and changes during this period are not known. Some of the differences in seasonal variations may have been affected by occupancy dating from November 1955.

Like moisture measurements, temperatures in and below the floor reflect conditions for prior periods of time from several hours to days and even seasons. Deep soil temperatures under newly constructed houses evidently take several years to stabilize and thus periodic measurements over a long period are essential. These temperatures change slowly, which makes frequent measurements unnecessary.

Figure 6 shows the average monthly outside air temperatures and soil temperatures 12 inches below the surface of the ground and 35 feet from the house for the period December 1954 to August 1957. The air temperatures are averages of Baltimore, Md., and Washington, D.C., monthly means. These air and soil temperatures are fairly well correlated, the maximum soil temperatures being generally 3° to 4° less than air temperatures and the minimums from 1° lower to 4° higher. The maximum variation in soil temperature from summer to winter during the 3-year period was about 47° F.

Average soil temperatures at various locations under the concrete slab floor are given in table 7. The maximum difference between the averages of the 2-inch and 96-inch levels below the slab was only about 11° F. The minimum winter temperature at the 2-inch level was about 60° and at the 96-inch level about 53°. The greatest differences occurred in spring and summer and smallest differences in the fall. The maximum summer to winter variation 2 inches below the slab amounted to only about 12° or about one-fourth that of the ground variation 35 feet from the house. This was undoubtedly affected considerably by the uniformity of house temperatures over the entire year.

As indicated in figure 7, at 96 inches below the slab the maximum variation was only about 10° F. The differences in deep soil temperatures under the slab were much less between 1956 and 1957 than between 1955 and 1956. A slight upward trend of temperatures was noted over the 3-year period.

Temperatures for four of the interior bays are illustrated in figure 8 and the data are given in tables 3 and 4. Averages of center temperatures for each bay were always higher than corresponding perimeter temperatures 2 inches below the slab although

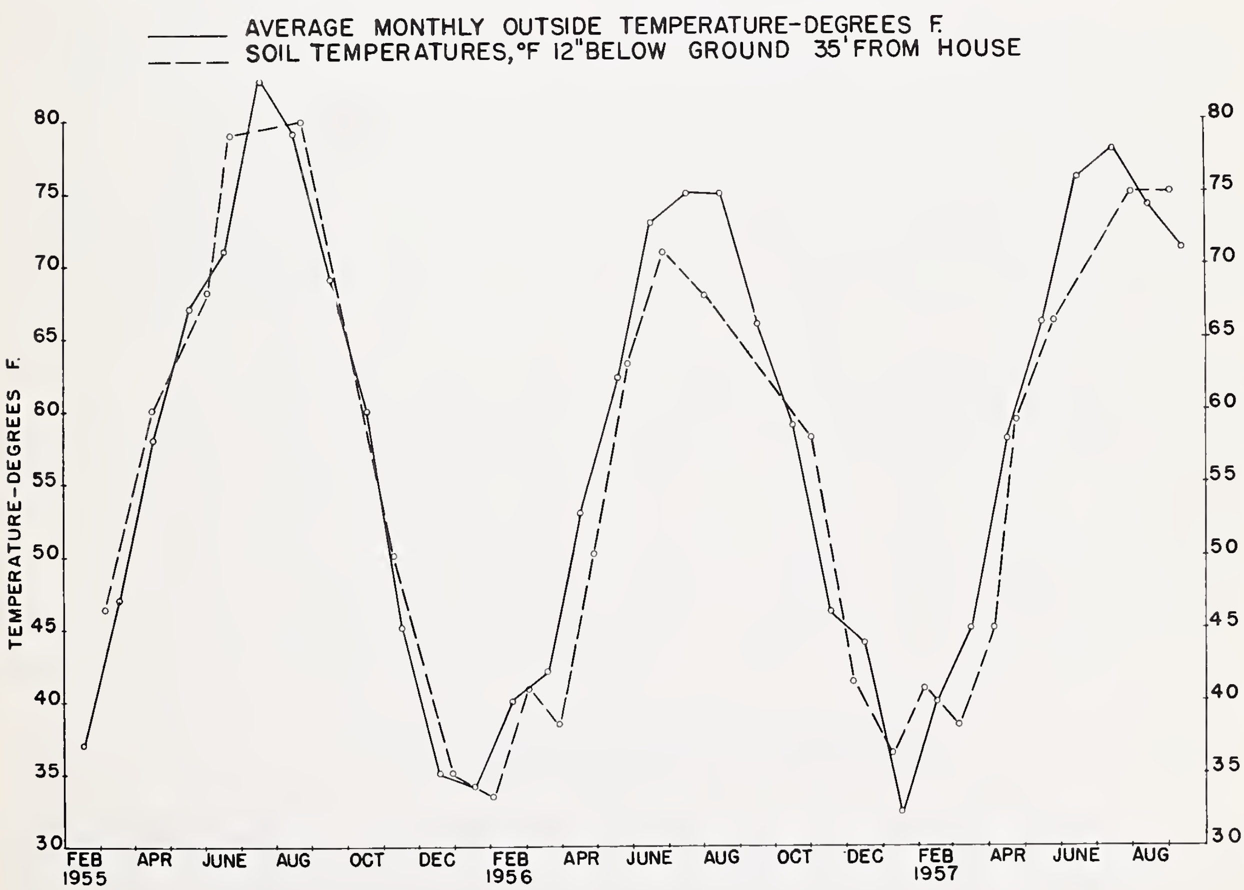

Figure 6.--Average monthly outside air temperatures and soil temperatures 12 inches below ground, December 1954 to August 1957.

TABLE 7.--Average soil temperature at various points under concrete slab floor, December 1954 to September 1957

Date measured	Point of measurement						
	At foundation 30 inches deep	Below floor					
		2 inches	22 inches	96 inches	2 inches		
					Perimeter	Middle of bay	Center of house
	°F.	°F.	°F.	°F.	°F.	°F.	°F.
1954: Dec. 17	49	61	59	59	56	62	62
1955:							
Feb. 3	45	60	57	56	56	60	60
Mar. 2	47	60	57	54	53	61	60
Apr. 15	52	64	61	54	56	66	64
May 12	58	64	62	57	62	64	63
June 2	62	67	66	58	58	68	66
June 21	69	69	66	58	69	71	69
July 26	69	72	69	61	73	73	72
Aug. 23	69	71	70	63	72	72	72
Nov. 9	57	66	65	63	62	66	68
Dec. 27	--	65	64	62	59	67	66
1956:							
Jan. 31	50	66	64	61	59	68	67
Feb. 28	51	67	65	60	62	69	67
Mar. 27	52	67	64	60	60	68	67
Apr. 27	55	68	65	59	64	69	69
May 29	61	69	68	62	68	71	70
June 29	69	71	71	65	71	73	72
Aug. 1	69	71	71	65	71	73	72
Sept. 4	70	72	72	67	73	73	73
Oct. 2	66	70	66	--	68	71	71
Oct. 30	63	69	69	66	67	70	70
Dec. 4	56	67	67	65	62	68	68
1957:							
Jan. 8	54	67	66	63	61	68	67
Feb. 5	51	66	65	61	61	65	65
Mar. 4	53	66	65	60	60	68	67
Apr. 2	54	68	65	60	63	70	68
Apr. 26	59	70	67	61	68	70	70
May 28	65	71	69	64	70	72	72
July 2	70	72	71	64	72	72	73
July 30	72	74	73	67	75	75	75
Sept. 2	70	74	72	67	74	74	74

maximum perimeter temperatures were higher in some instances. Differences in individual center and perimeter readings taken during the same run generally ranged from 3° to 6° in earth fill and 4° to 12° in gravel fill.

The average of center and perimeter temperatures 2 inches below the slab for the winter months after the house was occupied was about 1° lower in the gravel fill than in the earth fill. The perimeter temperature was about 2° lower. This indicates a greater heat loss to the earth especially at the perimeter of the earth fill, and the slightly better insulating effect of the air spaces in the gravel fill.

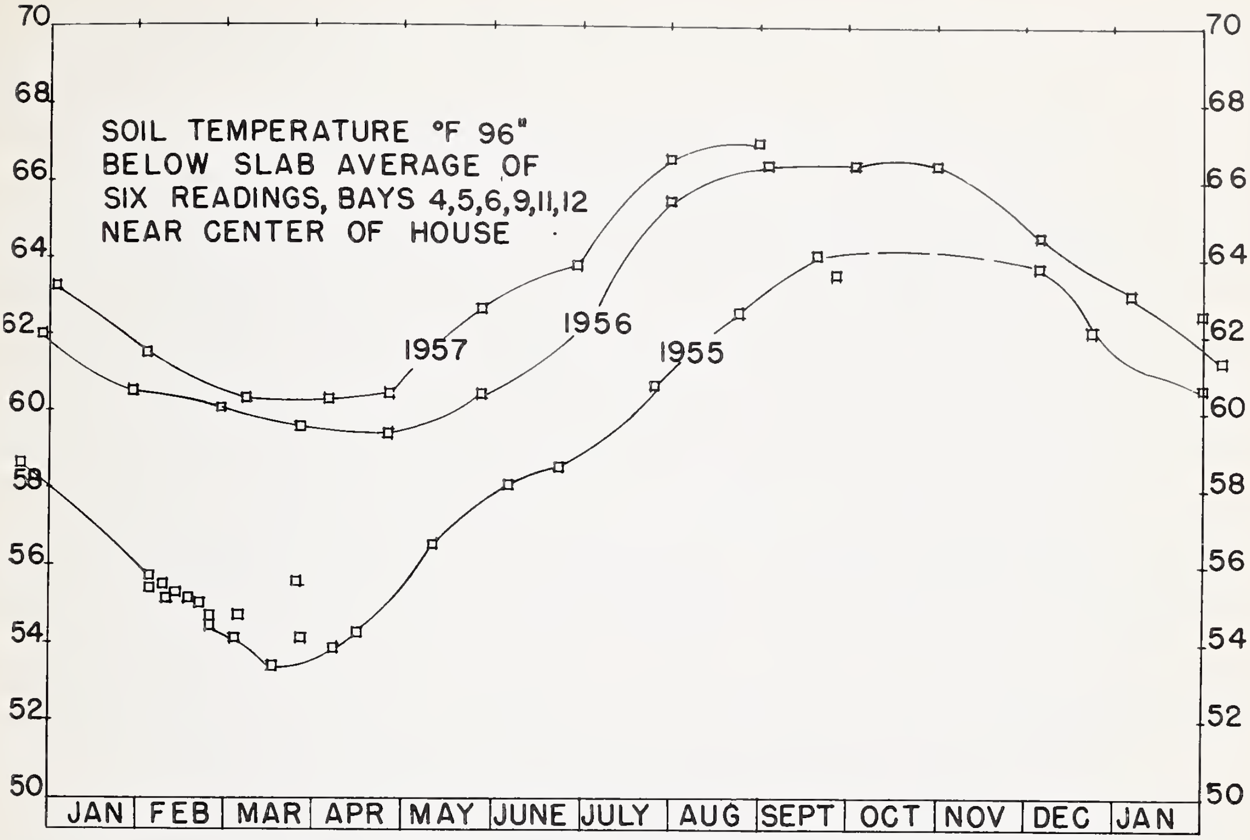

Figure 7.--Deep soil temperature comparisons for 1955, 1956, and 1957.

For both the 1956 and the 1957 sets of data the highest differences between the perimeter and center of the house under the slab seemed to occur during the January through March periods. The differences were small during late summer and fall. North edge perimeter temperatures average slightly lower--2° to 3°--than those on the south edge. Little difference occurred between the east and west ends of the house during July and August.

The use of a vapor barrier over both earth and gravel fill tended to reduce the average fill temperatures about 1°, and thus reduced heat loss. Theoretical calculations using still air surface coefficients for top and bottom surfaces of the slab with gravel fill beneath indicate that the vapor barrier would reduce the heat loss through the slab an average of 6 percent.

The vinyl floor tile was laid just prior to occupancy and, since inside air temperatures were higher after occupancy than before, it is difficult to evaluate the effect of the vinyl tile on heat loss through the floor. The use of a wool rug appeared to have lowered fill temperatures in that area about 2°, which reduced the calculated heat loss about 12 percent as compared with the tiled floor.

Floor Slab and Foundation Wall Movement

Figure 9 illustrates the movement of the floor slab and foundation wall over a limited time period. During the approximate 11-month period the foundation wall settled a maximum of 0.061 foot as compared with a maximum of 0.076 foot for the floor slab during the 6-month period. Thus the slab settled slightly more than the foundation wall, which resulted in movement between the slab and wall.

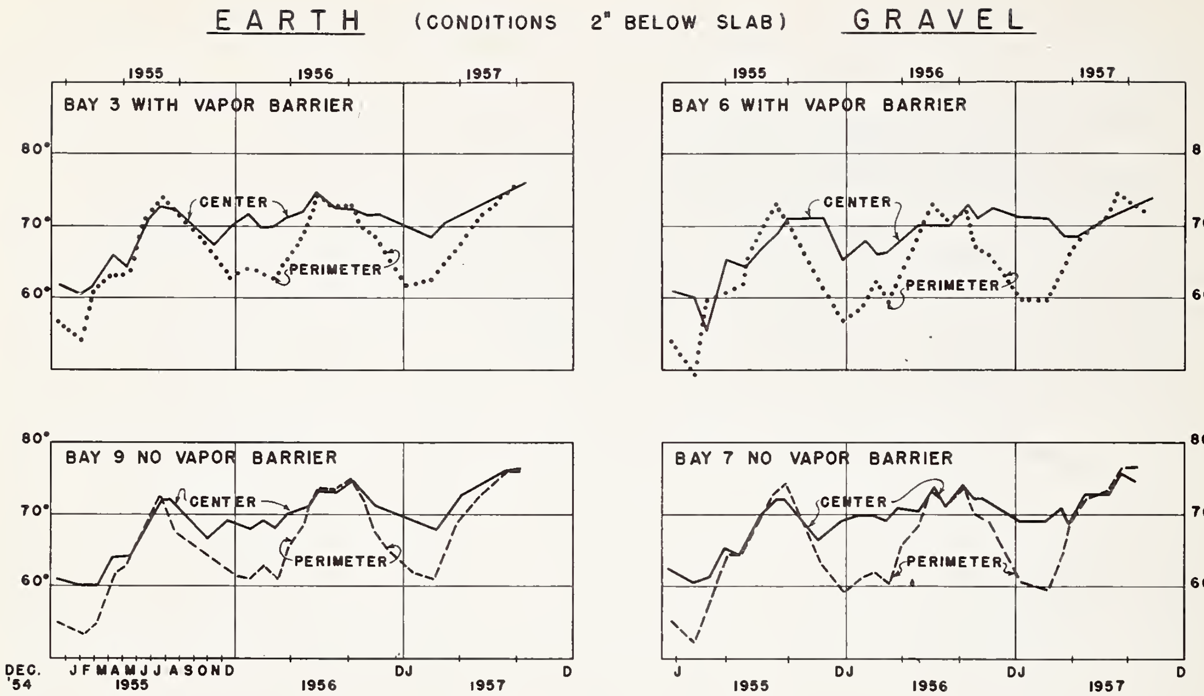

Figure 8.--Temperatures in earth and gravel fills 2 inches below slab floor.

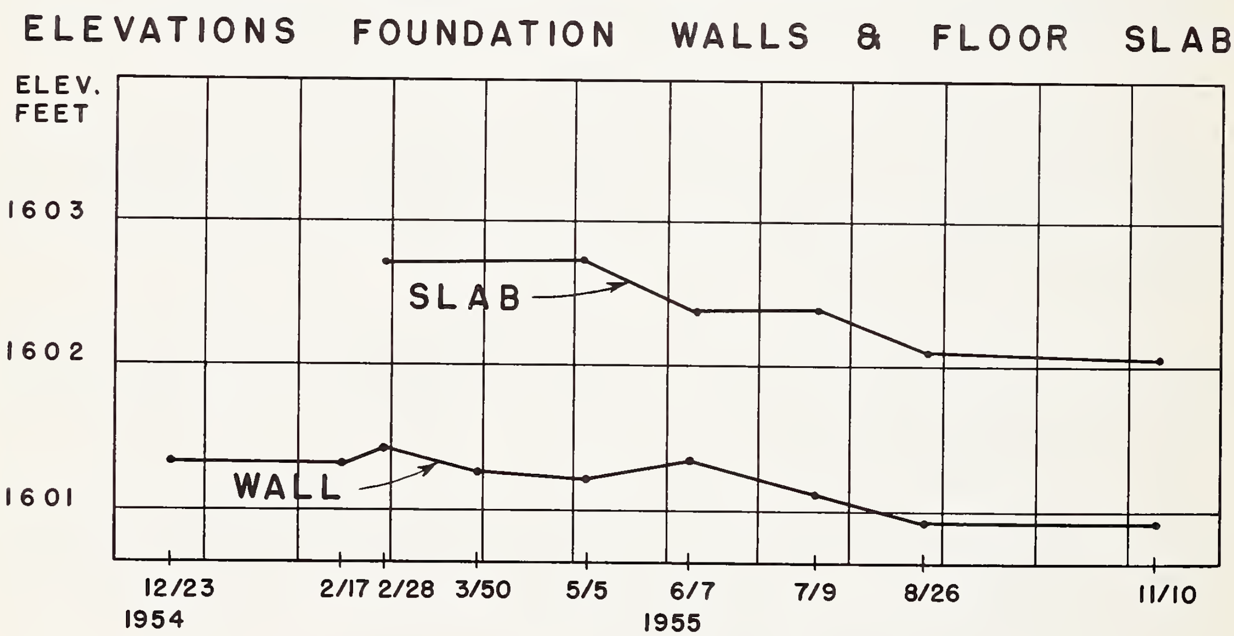

Figure 9.--Elevations of foundation wall and floor slab.

The concrete slab cracked over the earth bays on the north side of the house within the first year. Later these cracks extended over two of the gravel bays on the south side of the house. This was probably caused by volumetric changes in the clay used for the fill or by uneven settling of the slab resulting from the use of the two types of fill material (earth and gravel) under the sections of slab. Elevation readings of the slab and wall were not taken immediately after completing the floor and thus the changes during the first several months are not known.

The limited data prevent making any conclusions with regard to this phase of the study.

SUMMARY AND CONCLUSIONS

The trend of moisture index in earth fill 2 inches below the concrete slab floor with or without vapor barrier was generally downward with time. This trend appeared to be approaching equilibrium by the end of the study at a value approximating field capacity (about 24 percent).

Moisture index readings in the gravel fill 2 inches below the slab showed no consistent trend, were highly variable especially at the perimeter of bays, and did not approach equilibrium by the end of the study. Erratic behavior of the moisture elements in gravel can be expected since the elements were designed for use in intimate contact with earth. Some of the wide variation in readings undoubtedly resulted from the effect of temperature on the vapor pressure in gravel void spaces.

At 22 inches below the slab floor the soil moisture content ranged from 24 percent (field capacity) to 42 percent or more (standing water), and thus the soil appeared to be saturated during the entire period from December 1954 to September 1957. This soil moisture decreased slightly with time but was as high as or higher than outside the foundation most of the time.

Moisture index readings in the concrete slabs indicated a general upward movement of moisture through the slabs with and without vapor barriers and over both earth and gravel fills. A general upward trend of moisture index with time was indicated.

Moisture index readings in the slab indicated that the lower side of the slab over gravel bays was somewhat drier than that over earth bays, especially for the no-vapor-barrier condition. This would suggest some benefit from gravel fill, either with or without a vapor barrier, as compared with earth fill.

Blotter measurements indicated that the vapor barrier reduced the amount of moisture transmitted through the floor.

Average monthly outside air temperatures and soil temperatures 12 inches below the surface were highly correlated.

A slight upward trend of deep soil temperatures under the slab floor was noted over the period of almost 3 years. These temperatures under newly constructed houses apparently require several years to stabilize.

Average winter temperatures were always higher at the center of each interior bay studied than corresponding perimeter temperatures 2 inches below the slab. The use of larger test slabs or the omission of perimeter insulation would probably accentuate these differences.

Winter temperatures 2 inches below the slab averaged 1° lower in gravel than in earth fill; perimeter temperatures averaged 2° lower. This indicates a greater heat loss to the earth and the slightly better insulating effect of the air spaces in gravel fill.

A vapor barrier over both earth and gravel fill reduced the average fill temperature about 1°, which reduced heat loss. With changing seasons, the temperature may fluctuate slightly more for the edge of a slab without vapor barrier than with vapor barrier.

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